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BAND MODEL PARAMETERS FOR THE 4.3-MICRONS FUNDAMENTAL BAND OF CO_2 IN THE 100-3000 K TEMPERATURE RANGE

Stephen J. Young

Aerospace Corporation

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Band Model Parameters for the 4.3-μm Fundamental Band of CO_2 in the 100–3000°K Temperature Range

S. J. YOUNG
Chemistry and Physics Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, Calif. 90245

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FOR THE COMMANDER

Ronald C. Lawson

Ronald C. Lawson
1st Lt., United States Air Force
Office of Research Applications
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A set of band model parameters for CO_2 in the 4.3-μm spectral region and consistent for the entire temperature range from near-ambient atmospheric temperatures (~200°K) to gas combustion temperatures (~2500°K) is constructed. This construction is accomplished by joining together band model parameters derived from the AFCRL atmospheric absorption line data compilation (LINAVECO2 parameters) and parameters tabulated in the NASA Handbook of Infrared Radiation from Combustion Gases (NASACO2		

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parameters). The former set adequatel, describes the low-temperature variations of the parameters, but is inadequate for high-temperature applications. The latter set is suitable for high-temperature applications, but fails for low-temperature cases. Examples of the deficiencies of these two sets are presented by comparison of predicted spectra with experimental absorption and emission spectra for low- and high-temperature gas samples. The adequacy of the combined band model parameter set (COMBCO2 parameters) is demonstrated by comparison with the same experimental data. Examples of the construction of the combined set are given, and a tabulation of the parameter set is included as an Appendix.

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I. INTRODUCTION

In a previous report,[1] the need for sets of band model parameters for infrared active species that are internally consistent for the entire temperature range from near atmospheric ($\sim 250^\circ K$) to gas combustion values ($\sim 2500^\circ K$) was discussed. In that report, parameter sets for the 2.7-μm bands of H_2O and CO_2 were constructed by combining the low temperature variations of parameters derived from the Air Force Cambridge Research Laboratories (AFCRL) atmospheric absorption line data compilation[2] with the high-temperature variations published by General Dynamics in the NASA Handbook of Infrared Radiation from Combustion Gases.[3] The former parameters are valid near atmospheric temperatures and the latter for high temperatures. Conversely, outside the temperature region for which they are valid, both sets are decidedly inadequate. The combined sets were constructed to provide a consistent set that could be applied for all temperatures in the 100 to $3000^\circ K$ region. The present report extends this work to the 4.3-μm band of CO_2.

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[1] S. J. Young, Band Model Parameters for the 2.7-μm Bands of H_2O and CO_2 in the 100 to $3000^\circ K$ Temperature Range, TR-0076(6970)-4, The Aerospace Corp., El Segundo, Calif. (31 July 1975).

[2] R. A. McClatchey, W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfe, K. Fox, L. S. Rothman, and J. S. Garing, AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-006, Air Force Cambridge Research Laboratories, Bedford, Mass. (25 January 1973).

[3] C. B. Ludwig, W. Malkmus, J. E. Reardon, and J. A. L. Thompson, Handbook of Infrared Radiation from Combustion Gases, eds. R. Goulard and J. A. L. Thompson, NASA SP-3080, Marshall Space Flight Center, Huntsville, Ala. (1973).

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II. COMPONENT BAND MODEL PARAMETER SETS

A. Band Model Parameters From Line Data (LINAVE Parameters)

The procedure for deriving band model paramters appropriate to a Lorentz line statistical band model from line data is discussed in detail in Ref. 1. This procedure was applied to the AFCRL line data* in the 4.3-μm region for CO_2 to obtain the band model parameters $\bar{k}$ (mean absorption coefficient) and $1/\delta_e$ (mean effective line density) for the 97 spectral intervals from ν = 2010 to 2490 cm^{-1} by steps of 5 cm^{-1} with a spectral resolution $\Delta\nu$ = 5 cm^{-1} and for the 14 temperature values T = 100, 150, 200, 250, 300, 350, 400, 500, 750, 1000, 1500, 2000, 2500, and 3000°K. The line broadening parameter $\bar{\gamma}_0$ for nonresonant self-broadening was derived for the same spectral intervals. The third band model parameter $\bar{\gamma}$ (mean line half width at half height) is given in terms of $\bar{\gamma}_0$ by Eq. (30) or (32) of Ref. 1 and the CO_2 data of Table 1 of Ref. 1. The parameter set is designated for identification in this report as LINAVECO2.

B. NASA Parameters

The band model parameters for CO_2 from the NASA Handbook[3] are based on quantum mechanical calculations by Malkmus,[4] and are intended primarily for high-temperature application. The data for $\bar{k}$ are complete for the spectral region from 1900 to 2395 cm^{-1}. For $1/\delta_e$,** the data are given for the spectral region from 2000 to 2390 cm^{-1}. For both parameters, the data are given at the seven temperatures

*The line data compilation version dated 4 Feb 1975 by AFCRL was used in this work.

**This parameter is from the NASA Handbook tabulation for the single line grouping (SLG) model.

[4] W. Malkmus, J. Opt. Soc. Am. 53, 951 (1963).

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T = 300, 600, 1200, 1500, 1800, 2400, and 3000°K and reflect a spectral resolution of ~ 5 cm^{-1}. From this data compilation, a band model parameter set (designated NASACO2 in this report) was constructed* for ν = 1900 to 2400 cm^{-1} by 5 cm^{-1} steps and for the same seven temperatures as the NASA Handbook tabulation. The NASA unit for $\bar{k}$ is cm^{-1} at STP and was converted to the unit cm^{-1}/ atm by multiplication by 273/T. The $\bar{\gamma}_0$ coefficient is taken as a constant for all $\Delta\nu$ intervals with the value (Table 1, Ref. 1) $\bar{\gamma}_0$ = 0.09 cm^{-1}/atm.

C. Evaluation of Parameter Set

An evaluation of the LINAVECO2 and NASACO2 parameter sets was made by comparing absorption and emission spectra predicted by the respective sets with experimental absorption and emission measurements made on homogeneous, isothermal gas samples. The evaluation was made for both room-temperature and high-temperature gas samples.

1. Low-Temperature Evaluation (296°K)

Gryvnak et al.[5] have made high-resolution measurements of the absorption spectra of the 4.3-μm fundamental band of CO_2 at 296°K for a wide variety of optical thickness, CO_2 partial pressure, and total pressure (with N_2 as the foreign gas). For most of the sample experimental case, extensive tables are given from which the integrated absorptance between any two wavenumbers can be calculated.

*When required, linear interpolations with respect to ν were used to obtain the parameters for spectral positions not listed in the Handbook tabulation. The δ_e data at ν = 2000 cm^{-1} was assumed to prevail between ν = 1900 and 2000 cm^{-1}. The δ_e values at 2395 cm^{-1} were assumed to be 1/2 the values at 2390 cm^{-1}. All $\bar{k}$ and δ_e values were set to zero at ν = 2400 cm^{-1}. The spurious temperature variation of $\bar{k}$ between 1500 and 2400°K in the 1990 to 2090 cm^{-1} spectral region was modified by defining the parameter values at 1800°K to be the semilogarithmically interpolated value between the data at 1500 and 2400°K.

[5] D. A. Gryvnak, R. A. Patty, D. E. Burch, and E. E. Miller, Absorption by CO_2 between 1800 and 2850 cm^{-1}, U-3857, Aeronutronic Div., Philco-Ford Corp., Newport Beach, Calif. (15 Dec. 1966).

The solid curve of Figure 1 is the result obtained for their sample No. 100. The relevant data for this sample are: p = 0.132 atm, c = 2.5 × 10^{-4}, and L = 12110 cm. The optical depth is u = 0.399 atm cm and represents a case of moderate absorption. The curve was constructed to reflect a spectral resolution $\Delta\nu$ = 5 cm^{-1}. Figures 1a and 1b show the comparison of the experimental spectrum with the spectra computed with the LINAVECO2 and NASACO2 parameters, respectively. Both of the parameter sets give results that underestimate the experimental absorption near the band center. This underestimation may be due to the use of a statistical rather than a regular line spacing band model. Over the whole of the band, the LINAVECO2 parameters give an excellent fit to the experimental data, whereas the NASACO2 parameters give a poor fit.

A similar comparison was made for a more strongly absorbing sample (sample No. 40) in order to make a more sensitive comparison in the band wing region below 2300 cm^{-1}. For this sample, p = 0.132 atm, c = 4.0 × 10^{-3}, L = 46,900 cm, u = 24.8 atm cm, and, again, $\Delta\nu$ = 5 cm^{-1}. The results are presented in Figure 2 in the same format as Figure 1. Again, the excellency of the LINAVECO2 and the poorness of the NASACO2 parameter sets are demonstrated.

2. High-Temperature Evaluation (1500°K)

A high-temperature emission comparison was made between calculated emissivity spectra and an experimental spectrum of Burch and Gryvnak.[6] The experimental conditions were: p = 0.249 atm, c = 1.00, L = 7.75 cm, and T = 1500°K.

---

[6] D.E. Burch and D.A. Gryvnak, Infrared Radiation Emitted by Hot Gases and its Transmission Through Synthetic Atmospheres, U-1929, Aeronutronic Div., Philco-Ford Corp. Newport Beach, Calif. (31 October 1962).

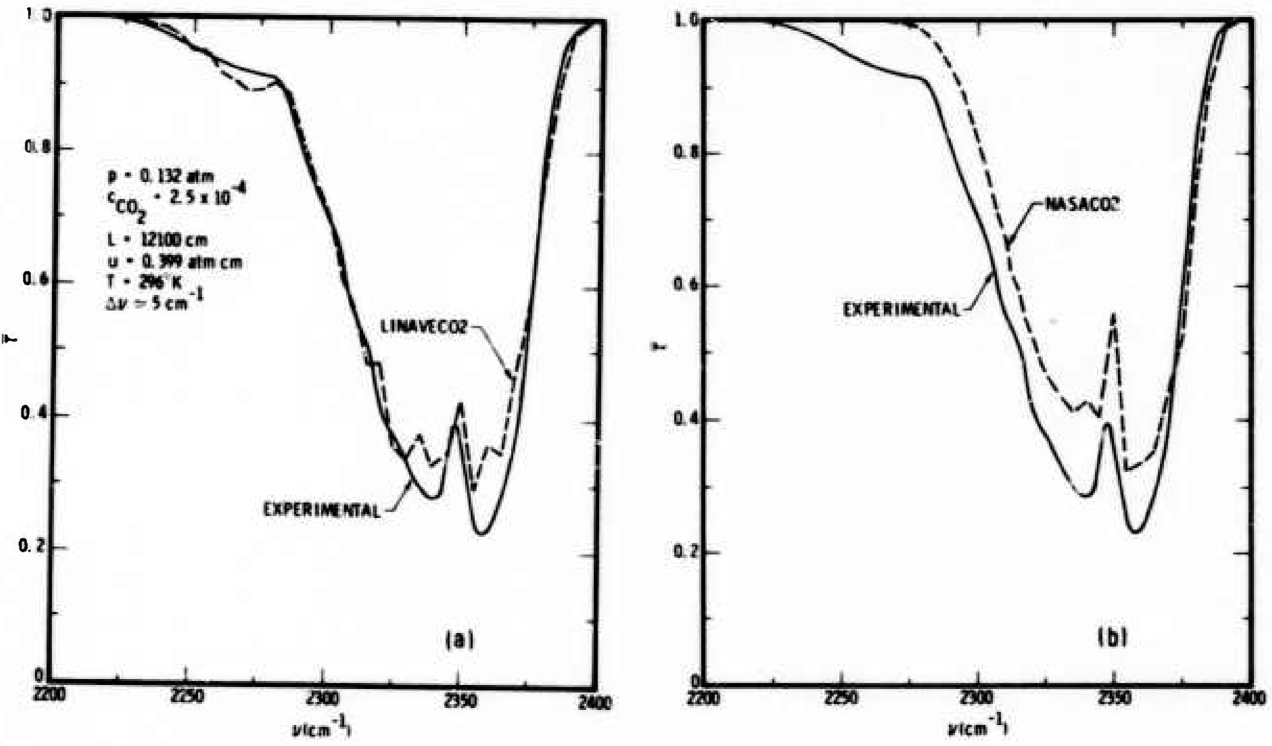

Figure 1. Low-Temperature Transmission Spectra for Moderate CO_2 Absorption. The LINAVECO2 (a) and NASACO2 (b) curves show spectra computed with the indicated band model parameter set. The EXPERIMENTAL curve is derived from the tables of Ref. 5 for sample No. 100 and for $\Delta\nu = 5\ cm^{-1}$.

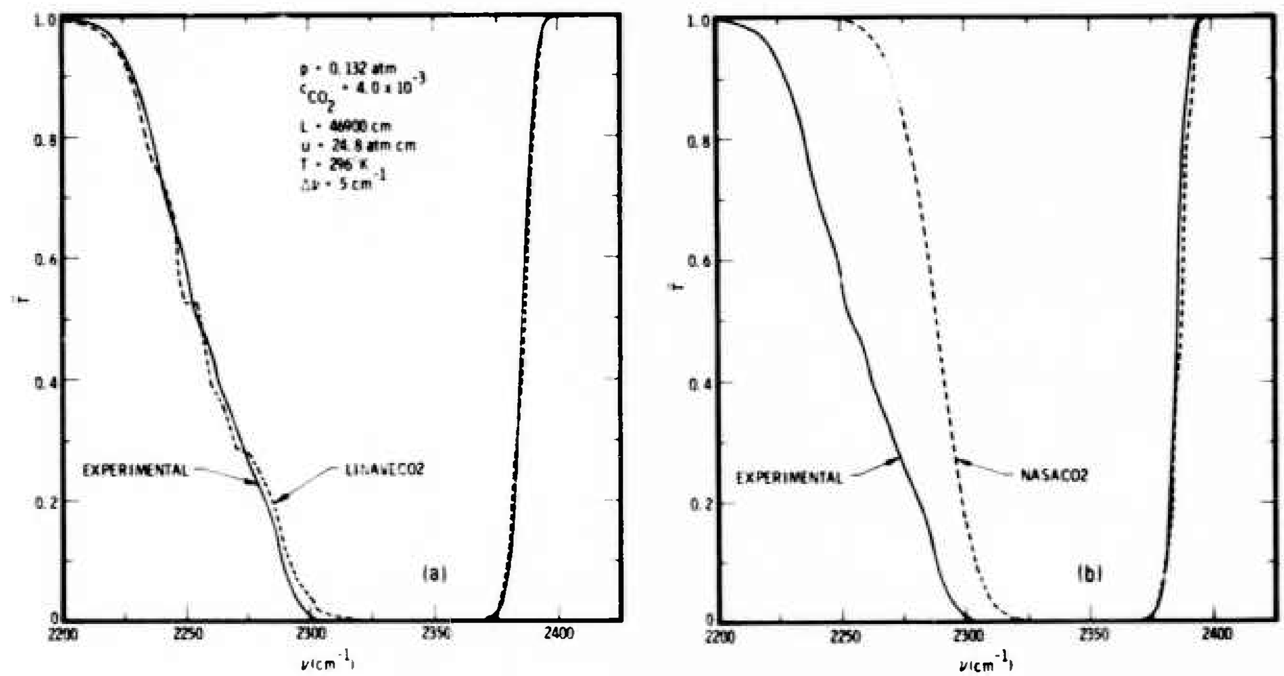

Figure 2. Low-Temperature Transmission Spectra for Strong CO_2 Absorption. The LINAVECO2 (a) and NASACO2 (b) curves show spectra computed with the indicated band model parameter set. The EXPERIMENTAL curve is derived from the tables of Ref. 5 for sample No. 40 and for $\Delta\nu = 5\ cm^{-1}$.

The optical depth is 1.93 atm cm and $\Delta\nu \sim 8\,cm^{-1}$. The comparison is shown in Figure 3. Here, we see the serious failing of the LINAVECO2 parameters when applied to high-temperature gases. Not only is the band-center emission seriouslv underestimated, but the entire band wing emission below $\sim 2200\ cm^{-1}$ is missing. The NASACO2 parameters, on the other hand, provide excellent agreement over the whole emission band.

These comparisons give the same qualitative result that was obtained for the 2.7-μm band of CO_2 in Ref. 1; namely, that the LINAVECO2 parameters are valid for low-temperature applications but not for high-temperature applications, whereas the validity of the NASA parameters is reversed.

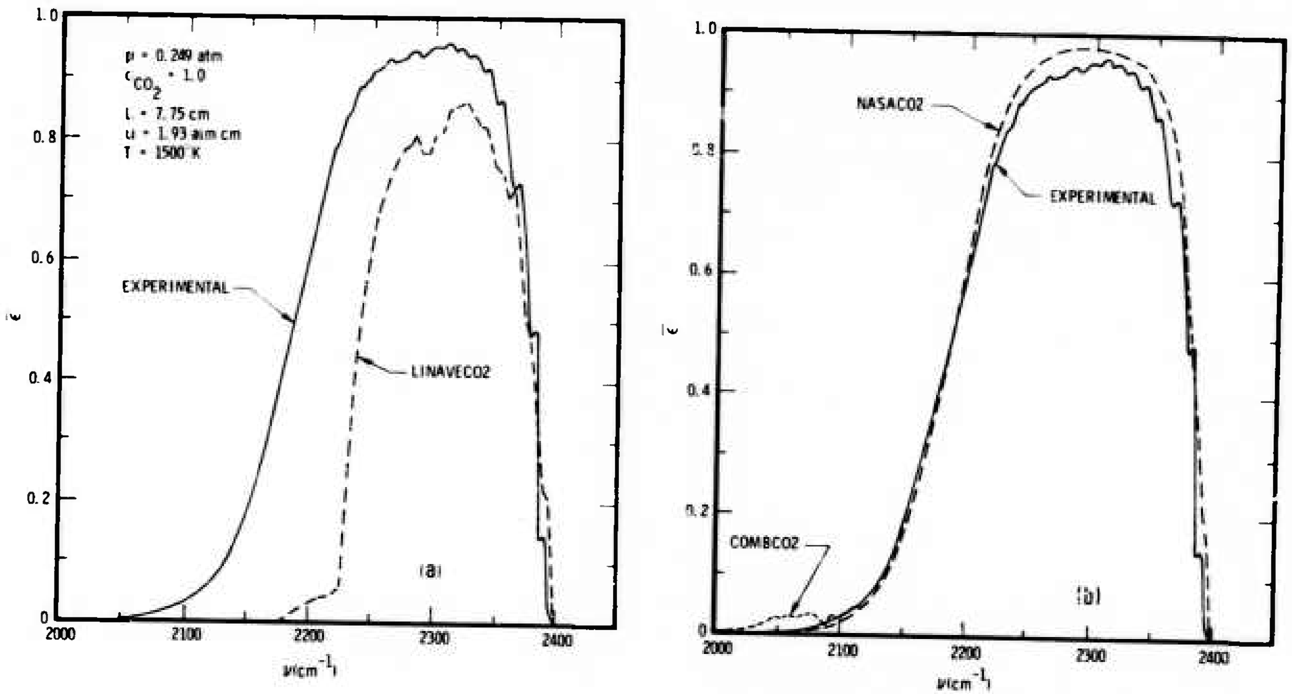

Figure 3. High-Temperature Emission Spectra for CO_2. The LINAVECO2 (a), NASACO2 (b) and COMBCO2 (b) curves show spectra computed with the indicated band model parameter set. The EXPERIMENTAL curve is taken from Ref. 6.

III. COMBINED PARAMETER SET (COMBCO2)

The synthesis of a consistent band model parameter set for the 4.3-μm band of CO_2 followed the general procedure given in Ref. 1. For each spectral interval, the LINAVECO2 and NASACO2 parameters were plotted as a function of temperature, and an interpolation was made between some low-temperature point on the LINAVECO2 curve to some high-temperature point on the NASACO2 curve. Some representative constructions are shown in Figures 4 and 5. The spectral positions ν = 2100, 2225, and 2350 cm^{-1} represent positions in the far wing, near wing, and band center, respectively. As a general rule, the choice of interpolation line (dashed curves in Figures 4 and 5) was relatively self-evident, and little iteration was required to get a best fit between spectra computed with the synthesized parameter set and the experimental spectra of Section IIC.

The final version of the synthesized set is designated COMBCO2 in this report. The band model parameters $\bar{k}$ (cm^{-1}/atm) and $1/\delta_e$ ($1/cm^{-1}$) are given for the 81 5 cm^{-1} spectral intervals from 2000 to 2400 cm^{-1} and the 10 temperatures T = 100, 200, 300, 500, 750, 1000, 1500, 2000, 2500, and 3000^{o}K. The broadening parameter $\bar{\gamma}_0$ from the LINAVECO2 set was used to represent this parameter in the combined set. A listing of the final parameter set is given in the Appendix.

Spectra for the homogeneous path conditions of Section IIC were generated with the final set to verify its validity. For both of the low-temperature cases, the spectra generated with the COMBCO2 parameters were indistinguishable (in plots) from those generated with the LINAVECO2 set. For the high-temperature case, the only difference between the spectra

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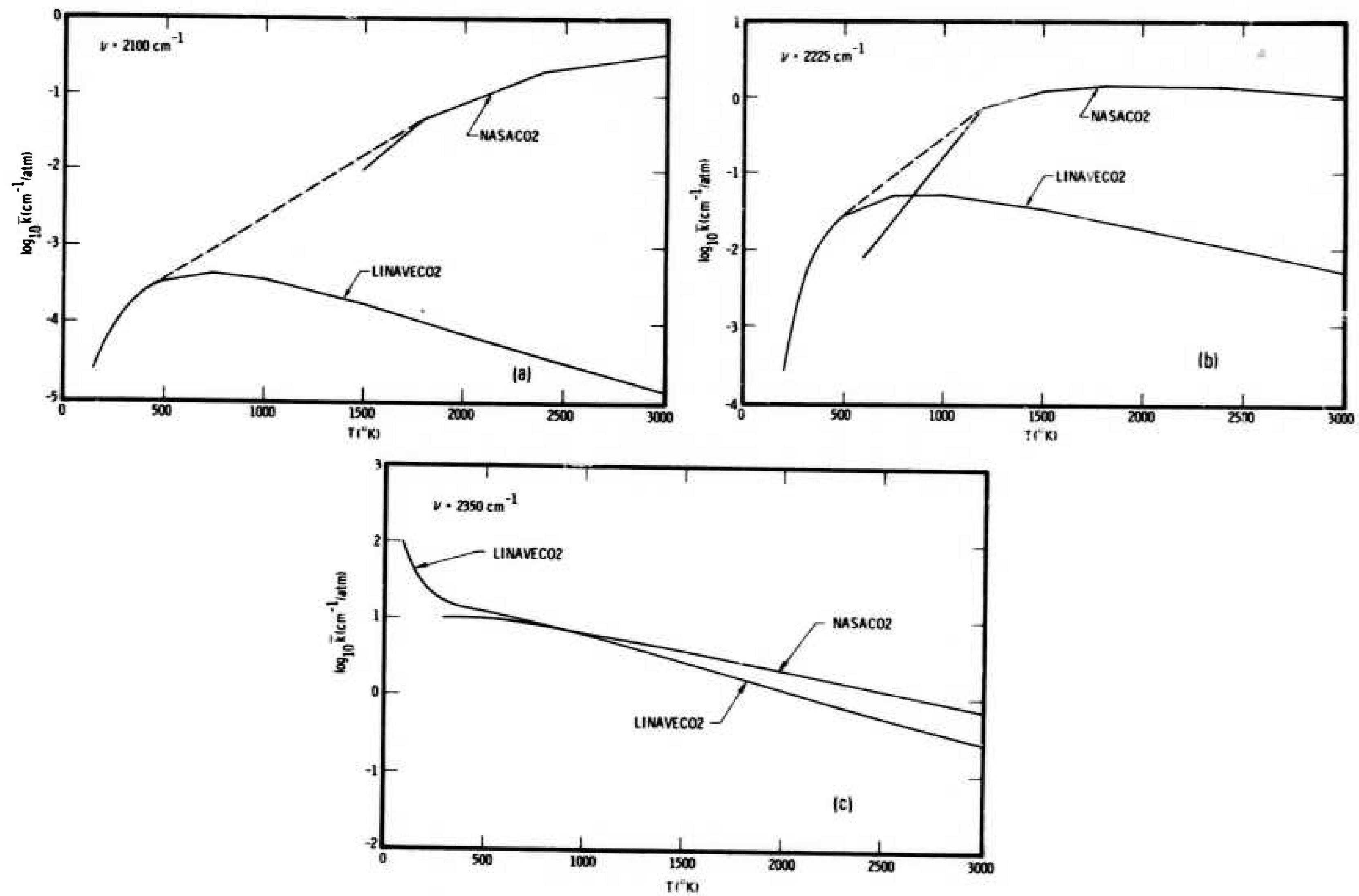

Figure 4. Variation of $\bar{k}$ with Temperature for Selected Spectral Intervals. The LINAVECO2 and NASACO2 curves are the variations for the indicated band model parameter set; dashed curves show assumed transitions from one curve to the other.

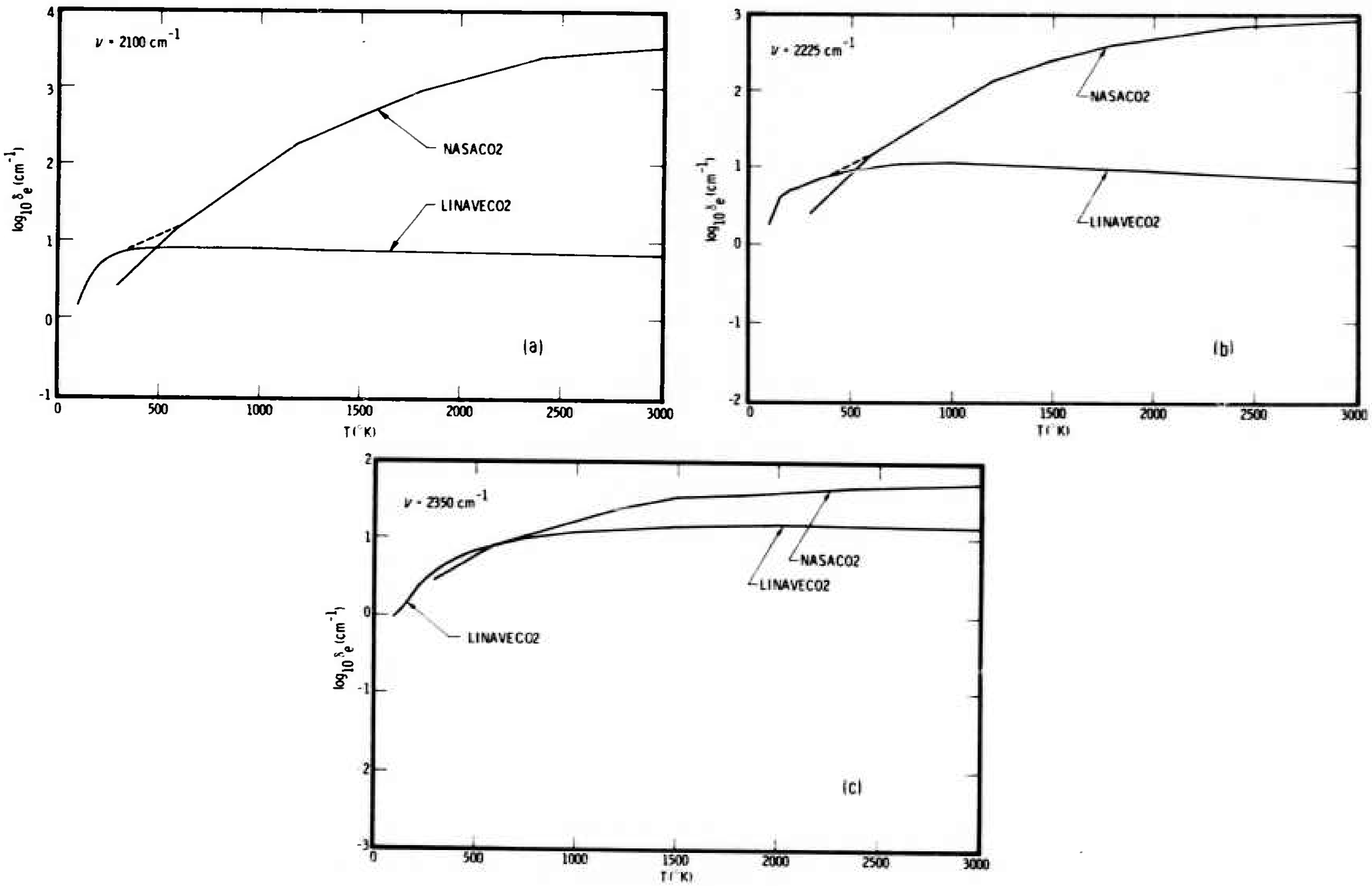

Figure 5. Variations of $1/\delta_e$ with Temperature for Selected Spectral Intervals. The LINAVECO2 and NASACO2 curves are the variations for the indicated band model parameter set; dashed curves show assumed transitions from one curve to the other.

computed with the COMBCO2 and NASACO2 sets is an increase in emission for the former set in the far band wing below $\sim 2100\ cm^{-1}$. This difference is indicated in Figure 3b by the short-dashed curve. Thus, the COMBCO2 parameter sets successfully reproduce spectra for both high- and low-temperature applications and can be expected to give adequate results for intermediate temperatures.

APPENDIX. COMBCO2 PARAMETER SET LISTING

A listing of the COMBCO2 band model parameters is given in the following table. IDNAME is simply an identification name for the parameter set. RESOLUTION is the value of $\Delta\nu$ appropriate for the set. ALPHA (1) through ALPHA (5) are the ratios of the efficiency of pressure broadening by the indicated mechanisms to that of nonresonant self-broadening. ALPHA (6) is the atomic mass of the absorbing species. the WAVENUMBER array lists the center values of all the $\Delta\nu$ intervals included in the set. NW is the number of such intervals. The TEMPERATURE array similarly lists the temperatures for which the data are tabulated. NT is the number of such temperatures. The ABSORPTION COEFFICIENT array is $\bar{k}$. The first column of this array is the interval center wavenumber, and the rows are the values at the temperatures of the TEMPERATURE array. The EFFECTIVE LINE DENSITY array is the parameter $1/\delta_e$ and is presented in the same format as $\bar{k}$. The MEAN LINE WIDTH array is the parameter $\bar{\gamma}_0$ for nonresonant self-broadening at STP. The values correspond to the wavenumbers listed in the WAVENUMBER array.

BAND MODEL PARAMETERS

IDNAME	COMBCO2A	
RESOLUTION(CM-1)	5.0000	
ALPHA(1)	.1110E+00	RESONANT SELF-BROADENING
ALPHA(2)	.7790E+00	FOREIGN-GAS BROADENING(H2O)
ALPHA(3)	0.	FOREIGN-GAS BROADENING(CO2)
ALPHA(4)	.7780E+00	FOREIGN-GAS BROADENING(N2)
ALPHA(5)	.6110E+00	FOREIGN-GAS BROADENING(O2)
ALPHA(6)	.4400E+02	ATOMIC WEIGHT(AMU)

WAVENUMBER(WN) ARRAY(CM-1)   NW= 81

2.000E+03	2.005E+03	2.010E+03	2.015E+03	2.020E+03	2.025E+03	2.030E+03	2.035E+03	2.040E+03	2.045E+03
2.050E+03	2.055E+03	2.060E+03	2.065E+03	2.070E+03	2.075E+03	2.080E+03	2.085E+03	2.090E+03	2.095E+03
2.100E+03	2.105E+03	2.110E+03	2.115E+03	2.120E+03	2.125E+03	2.130E+03	2.135E+03	2.140E+03	2.145E+03
2.150E+03	2.155E+03	2.160E+03	2.165E+03	2.170E+03	2.175E+03	2.180E+03	2.185E+03	2.190E+03	2.195E+03
2.200E+03	2.205E+03	2.210E+03	2.215E+03	2.220E+03	2.225E+03	2.230E+03	2.235E+03	2.240E+03	2.245E+03
2.250E+03	2.255E+03	2.260E+03	2.265E+03	2.270E+03	2.275E+03	2.280E+03	2.285E+03	2.290E+03	2.295E+03
2.300E+03	2.305E+03	2.310E+03	2.315E+03	2.320E+03	2.325E+03	2.330E+03	2.335E+03	2.340E+03	2.345E+03
2.350E+03	2.355E+03	2.360E+03	2.365E+03	2.370E+03	2.375E+03	2.380E+03	2.385E+03	2.390E+03	2.395E+03
2.400E+03									

TEMPERATURE(T) ARRAY(DEGK)   NT= 10

1.000E+02	2.000E+02	3.000E+02	5.000E+02	7.500E+02	1.000E+03	1.500E+03	2.000E+03	2.500E+03	3.000E+03

ABSORPTION COEFFICIENT(K) ARRAY(CM-1/ATM)

2000.00	0.	0.	0.	0.	0.	0.	2.375E-05	8.500E-03	1.950E-02	5.968E-02
2005.00	0.	0.	0.	0.	0.	0.	3.987E-05	1.000E-02	2.250E-02	5.626E-02
2010.00	1.641E-06	1.034E-05	1.310E-05	1.146E-05	1.504E-05	1.745E-05	5.598E-05	1.147E-02	2.444E-02	7.284E-02
2015.00	3.373E-06	1.914E-05	1.761E-05	2.214E-05	5.059E-05	6.123E-05	1.496E-03	1.332E-02	2.814E-02	9.039E-02
2020.00	2.645E-05	2.698E-05	2.124E-05	5.543E-05	1.165E-04	3.484E-04	3.116E-03	1.519E-02	3.184E-02	8.795E-02
2025.00	5.439E-05	2.638E-05	2.549E-05	8.983E-05	1.424E-04	4.202E-04	3.658E-03	1.752E-02	3.643E-02	9.671E-02
2030.00	6.341E-05	2.770E-05	6.533E-05	2.416E-04	2.835E-04	7.316E-04	4.873E-03	1.987E-02	4.101E-02	1.055E-01
2035.00	1.540E-04	6.406E-05	1.626E-04	3.712E-04	7.758E-04	1.634E-03	7.192E-03	2.287E-02	4.694E-02	1.177E-01
2040.00	2.849E-05	1.080E-04	3.279E-04	6.327E-04	1.227E-03	2.379E-03	8.945E-03	2.587E-02	5.287E-02	1.299E-01
2045.00	2.515E-05	2.893E-04	6.265E-04	1.017E-03	1.849E-03	3.363E-03	1.112E-02	2.976E-02	6.008E-02	1.405E-01
2050.00	1.997E-04	1.169E-03	1.535E-03	2.236E-03	3.579E-03	5.725E-03	1.467E-02	3.365E-02	6.728E-02	1.512E-01
2055.00	8.116E-04	1.828E-03	1.649E-03	1.097E-03	2.067E-03	3.896E-03	1.383E-02	3.857E-02	7.639E-02	1.647E-01
2060.00	2.629E-03	2.614E-03	1.814E-03	1.382E-03	2.092E-03	4.046E-03	1.513E-02	4.349E-02	8.548E-02	1.782E-01
2065.00	5.118E-03	2.733E-03	1.653E-03	1.146E-03	1.030E-03	2.437E-03	1.364E-02	4.982E-02	9.676E-02	1.937E-01
2070.00	6.607E-03	2.226E-03	1.229E-03	8.385E-04	3.521E-04	2.171E-03	1.408E-02	5.615E-02	1.059E-01	2.092E-01
2075.00	1.775E-02	7.180E-03	3.913E-03	1.928E-03	1.364E-03	3.205E-03	1.769E-02	6.395E-02	1.223E-01	2.321E-01
2080.00	2.979E-03	2.520E-03	2.465E-03	2.023E-03	1.489E-03	3.522E-03	1.970E-02	7.173E-02	1.365E-01	2.550E-01
2085.00	1.899E-03	4.158E-04	3.253E-04	5.237E-04	7.627E-04	1.943E-03	1.261E-02	5.887E-02	1.525E-01	2.718E-01

2090.00	2.187E-04	1.232E-04	1.363E-04	4.314E-04	6.968E-04	1.589E-03	8.247E-03	4.205E-02	1.686E-01	2.886E-01
2095.00	1.212E-05	3.266E-04	1.023E-03	1.986E-03	3.415E-03	5.871E-03	1.735E-02	5.731E-02	1.882E-01	3.104E-01
2100.00	8.182E-06	4.924E-05	1.302E-04	3.432E-04	8.740E-04	2.226E-03	1.444E-02	7.191E-02	2.078E-01	3.322E-01
2105.00	5.943E-06	6.161E-05	1.721E-04	4.477E-04	1.124E-03	2.822E-03	1.779E-02	8.481E-02	2.308E-01	3.563E-01
2110.00	1.626E-06	5.768E-05	1.762E-04	4.850E-04	1.237E-03	3.154E-03	2.050E-02	9.763E-02	2.538E-01	3.804E-01
2115.00	3.456E-07	3.636E-05	1.434E-04	4.212E-04	1.143E-03	3.101E-03	2.282E-02	1.143E-01	2.821E-01	4.123E-01
2120.00	4.703E-07	2.774E-05	9.470E-05	3.882E-04	1.184E-03	3.141E-03	2.541E-02	1.309E-01	3.103E-01	4.442E-01
2125.00	5.208E-07	1.996E-05	6.088E-05	2.075E-04	7.361E-04	2.612E-03	3.287E-02	1.523E-01	3.411E-01	4.712E-01
2130.00	1.834E-06	1.096E-04	3.530E-04	8.509E-04	2.233E-03	5.858E-03	4.033E-02	1.735E-01	3.718E-01	4.981E-01
2135.00	1.832E-07	6.573E-06	2.812E-05	1.836E-04	8.355E-04	3.802E-03	5.144E-02	2.008E-01	4.073E-01	5.278E-01
2140.00	2.121E-07	1.017E-05	3.855E-05	2.157E-04	1.027E-03	4.890E-03	6.255E-02	2.280E-01	4.427E-01	5.574E-01
2145.00	5.012E-08	4.755E-06	2.781E-05	1.967E-04	1.007E-03	5.156E-03	7.871E-02	2.634E-01	4.898E-01	6.115E-01
2150.00	9.898E-09	2.285E-06	2.088E-05	2.057E-04	1.074E-03	5.606E-03	9.486E-02	2.988E-01	5.363E-01	6.657E-01
2155.00	1.168E-09	9.736E-07	1.184E-05	1.166E-04	7.700E-04	5.085E-03	1.177E-01	3.408E-01	5.762E-01	6.820E-01
2160.00	1.392E-10	4.578E-07	7.843E-06	1.059E-04	8.038E-04	6.100E-03	1.406E-01	3.823E-01	6.154E-01	6.982E-01
2165.00	1.592E-10	1.164E-06	1.966E-05	1.740E-04	1.225E-03	8.626E-03	1.727E-01	4.344E-01	6.632E-01	7.285E-01
2170.00	1.211E-11	1.051E-07	3.117E-06	7.056E-05	7.576E-04	8.134E-03	2.047E-01	4.856E-01	7.109E-01	7.588E-01
2175.00	5.084E-12	1.048E-07	4.595E-06	9.455E-05	1.008E-03	1.074E-02	2.497E-01	5.469E-01	7.620E-01	7.890E-01
2180.00	5.185E-13	9.964E-08	7.128E-06	1.864E-04	1.713E-03	1.574E-02	2.945E-01	6.077E-01	8.129E-01	8.190E-01
2185.00	3.086E-13	1.925E-07	1.448E-05	5.102E-04	3.587E-03	2.521E-02	3.556E-01	6.818E-01	8.799E-01	8.965E-01
2190.00	2.225E-12	2.793E-07	1.877E-05	9.164E-04	5.712E-03	3.560E-02	4.166E-01	7.556E-01	9.463E-01	9.537E-01
2195.00	9.040E-12	8.815E-07	4.310E-05	1.641E-03	9.055E-03	4.996E-02	4.976E-01	8.368E-01	9.963E-01	9.619E-01
2200.00	2.253E-11	1.302E-06	6.589E-05	2.617E-03	1.329E-02	6.746E-02	5.788E-01	9.176E-01	1.047E+00	9.701E-01
2205.00	1.129E-10	3.666E-05	1.606E-04	4.790E-03	2.125E-02	9.424E-02	6.830E-01	1.007E+00	1.100E+00	9.901E-01
2210.00	5.604E-10	9.419E-06	4.143E-04	8.620E-03	3.355E-02	1.306E-01	7.873E-01	1.098E+00	1.152E+00	1.010E+00
2215.00	3.981E-09	2.402E-05	8.242E-04	1.248E-02	4.595E-02	1.692E-01	9.176E-01	1.192E+00	1.201E+00	1.026E+00
2220.00	5.395E-08	3.363E-05	2.007E-03	2.060E-02	6.839E-02	2.270E-01	1.048E+00	1.291E+00	1.251E+00	1.042E+00
2225.00	6.363E-07	[illegible]	4.006E-03	2.818E-02	8.992E-02	2.869E-01	1.206E+00	1.395E+00	1.315E+00	1.093E+00
2230.00	5.899E-06	8.961E-04	9.062E-03	4.562E-02	1.315E-01	3.788E-01	1.365E+00	1.504E+00	1.381E+00	1.144E+00
2235.00	4.728E-05	4.274E-03	2.517E-02	7.873E-02	1.997E-01	5.067E-01	1.546E+00	1.599E+00	1.414E+00	1.139E+00
2240.00	3.630E-04	1.015E-02	3.996E-02	9.796E-02	2.683E-01	5.603E-01	1.727E+00	1.699E+00	1.443E+00	1.135E+00
2245.00	1.487E-03	2.394E-02	6.732E-02	1.299E-01	3.709E-01	7.462E-01	1.927E+00	1.799E+00	1.473E+00	1.129E+00
2250.00	9.800E-03	5.397E-02	1.644E-01	2.210E-01	5.577E-01	1.033E+00	2.126E+00	1.882E+00	1.439E+00	1.125E+00
2255.00	3.074E-02	1.358E-01	1.811E-01	2.323E-01	7.375E-01	1.338E+00	2.344E+00	2.001E+00	1.604E+00	1.265E+00
2260.00	1.766E-01	3.864E-01	3.682E-01	3.521E-01	9.533E-01	1.583E+00	2.544E+00	2.115E+00	1.709E+00	1.405E+00
2265.00	6.892E-01	6.853E-01	4.834E-01	4.607E-01	1.319E+00	2.023E+00	2.761E+00	2.156E+00	1.648E+00	1.272E+00
2270.00	1.795E+00	3.412E-01	5.295E-01	6.149E-01	1.779E+00	2.492E+00	2.948E+00	2.188E+00	1.586E+00	1.139E+00
2275.00	2.709E+00	9.264E-01	4.784E-01	8.930E-01	2.393E+00	3.019E+00	3.141E+00	2.236E+00	1.573E+00	1.127E+00
2280.00	1.768E+00	4.966E-01	3.335E-01	1.344E+00	3.163E+00	3.571E+00	3.298E+00	2.265E+00	1.560E+00	1.075E+00
2285.00	1.443E+00	4.006E-01	3.974E-01	1.937E+00	3.861E+00	3.996E+00	3.471E+00	2.305E+00	1.538E+00	1.040E+00
2290.00	3.017E+00	9.597E-01	8.751E-01	2.981E+00	4.708E+00	4.600E+00	3.567E+00	2.390E+00	1.516E+00	1.006E+00
2295.00	2.356E+00	1.442E+00	1.533E+00	4.048E+00	5.348E+00	5.012E+00	3.640E+00	2.354E+00	1.595E+00	1.102E+00
2300.00	8.201E-01	1.117E+00	2.320E+00	6.020E+00	6.794E+00	5.746E+00	3.716E+00	2.422E+00	1.674E+00	1.198E+00
2305.00	1.255E-01	1.462E+00	4.924E+00	9.822E+00	8.927E+00	6.539E+00	3.709E+00	2.307E+00	1.530E+00	1.113E+00
2310.00	1.274E-01	2.523E+00	7.153E+00	1.135E+01	9.258E+00	6.790E+00	3.667E+00	2.362E+00	1.545E+00	1.027E+00
2315.00	8.720E-01	8.740E+00	1.567E+01	1.635E+01	1.077E+01	7.211E+00	3.727E+00	2.425E+00	1.633E+00	9.682E-01
2320.00	2.880E+00	1.337E+01	1.773E+01	1.476E+01	9.079E+00	6.728E+00	3.771E+00	2.285E+00	1.436E+00	9.088E-01
2325.00	1.738E+01	3.836E+01	3.632E+01	2.202E+01	1.129E+01	7.287E+00	3.702E+00	2.221E+00	1.372E+00	8.455E-01
2330.00	6.900E+01	6.837E+01	4.773E+01	2.254E+01	1.049E+01	7.662E+00	3.711E+00	2.181E+00	1.305E+00	7.821E-01
2335.00	1.054E+02	6.119E+01	3.519E+01	1.502E+01	1.027E+01	7.018E+00	3.736E+00	2.124E+00	1.253E+00	8.123E-01
2340.00	2.527E+02	9.743E+01	4.883E+01	1.897E+01	1.048E+01	7.019E+00	3.851E+00	2.217E+00	1.353E+00	8.424E-01
2345.00	2.350E+02	6.641E+01	3.373E+01	1.550E+01	9.766E+00	6.918E+00	3.700E+00	1.952E+00	1.095E+00	7.477E-01
2350.00	1.005E+02	2.735E+01	1.658E+01	1.217E+01	8.978E+00	6.623E+00	3.691E+00	2.013E+00	1.134E+00	6.529E-01
2355.00	3.779E+02	1.130E+02	5.399E+01	2.291E+01	1.267E+01	8.161E+00	3.620E+00	2.077E+00	1.161E+00	5.685E-01
2360.00	2.367E+02	1.050E+02	5.555E+01	2.392E+01	1.239E+01	8.251E+00	3.726E+00	1.792E+00	9.104E-01	4.840E-01
2365.00	1.208E+02	1.020E+02	6.670E+01	3.303E+01	1.624E+01	9.159E+00	3.529E+00	1.706E+00	8.647E-01	4.037E-01
2370.00	1.882E+01	4.575E+01	4.209E+01	2.615E+01	1.476E+01	8.320E+00	3.092E+00	1.366E+00	6.448E-01	3.233E-01

2375.00	1.394E+00	1.458E+01	2.248E+01	1.889E+01	1.162E+01	6.773E+00	2.632E+00	1.215E+00	5.761E-01	2.616E-01
2380.00	1.849E-02	1.772E+00	5.834E+00	8.962E+00	6.662E+00	4.603E+00	1.982E+00	9.095E-01	3.472E-01	1.595E-01
2385.00	7.912E-05	1.235E-01	1.089E+00	3.846E+00	4.232E+00	3.101E+00	1.535E+00	7.273E-01	3.283E-01	1.149E-01
2390.00	5.607E-09	1.077E-03	4.753E-02	6.339E-01	1.385E+00	1.402E+00	7.549E-01	3.424E-01	1.553E-01	7.044E-02
2395.00	4.343E-12	1.689E-05	5.461E-04	4.566E-02	2.700E-01	4.684E-01	4.836E-01	2.904E-01	1.249E-01	2.595E-02
2400.00	1.565E-11	6.901E-07	1.764E-05	1.385E-04	2.292E-04	2.053E-04	1.006E-04	4.300E-05	1.931E-05	9.709E-06

EFFECTIVE LINE DENSITY(D) ARRAY(LINES/CM-1)

2000.00	0.	0.	0.	0.	0.	0.	4.008E+02	1.080E+03	3.300E+03	7.015E+03
2005.00	0.	0.	0.	0.	0.	0.	4.008E+02	1.080E+03	3.300E+03	6.940E+03
2010.00	6.231E-01	1.281E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.289E+03	3.261E+03	6.865E+03
2015.00	6.580E-01	1.296E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.288E+03	3.239E+03	6.678E+03
2020.00	7.209E-01	1.357E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.287E+03	3.218E+03	6.492E+03
2025.00	8.064E-01	1.234E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.285E+03	3.191E+03	6.305E+03
2030.00	1.262E+00	2.335E+00	3.685E+00	9.181E+00	2.737E+01	7.898E+01	4.008E+02	1.283E+03	3.165E+03	6.119E+03
2035.00	3.327E+00	4.242E+00	5.767E+00	1.066E+01	2.737E+01	7.898E+01	4.008E+02	1.282E+03	3.142E+03	5.932E+03
2040.00	3.915E+00	5.041E+00	6.564E+00	1.113E+01	2.737E+01	7.898E+01	4.008E+02	1.281E+03	3.119E+03	5.746E+03
2045.00	3.083E+00	4.201E+00	5.725E+00	1.063E+01	2.737E+01	7.898E+01	4.008E+02	1.280E+03	3.097E+03	5.559E+03
2050.00	3.600E+00	4.756E+00	6.284E+00	1.097E+01	2.737E+01	7.898E+01	4.008E+02	1.280E+03	3.076E+03	5.373E+03
2055.00	9.031E-01	1.432E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.277E+03	3.041E+03	5.186E+03
2060.00	7.339E-01	1.369E+00	2.553E+00	8.123E+00	2.737E+01	7.898E+01	4.008E+02	1.274E+03	3.006E+03	5.000E+03
2065.00	7.456E-01	1.025E+00	1.852E+00	7.299E+00	2.737E+01	7.898E+01	4.008E+02	1.271E+03	2.963E+03	4.776E+03
2070.00	8.883E-01	1.219E+00	2.117E+00	7.632E+00	2.737E+01	7.898E+01	4.008E+02	1.269E+03	2.933E+03	4.552E+03
2075.00	2.599E+00	3.050E+00	4.132E+00	9.245E+00	2.737E+01	7.898E+01	4.008E+02	1.265E+03	2.893E+03	4.402E+03
2080.00	2.617E+00	3.982E+00	5.702E+00	1.062E+01	2.737E+01	7.898E+01	4.008E+02	1.262E+03	2.857E+03	4.253E+03
2085.00	7.264E-01	1.708E+00	3.923E+00	9.525E+00	2.737E+01	7.898E+01	4.008E+02	9.923E+02	1.555E+03	4.066E+03
2090.00	6.417E-01	1.810E+00	4.661E+00	9.928E+00	2.737E+01	7.898E+01	4.008E+02	1.250E+03	2.748E+03	3.880E+03
2095.00	5.243E+00	1.091E+01	1.362E+01	1.710E+01	3.998E+01	9.347E+01	4.008E+02	9.876E+02	1.533E+03	3.731E+03
2100.00	1.392E+00	4.515E+00	6.693E+00	1.120E+01	2.737E+01	7.898E+01	4.008E+02	1.228E+03	2.655E+03	3.582E+03
2105.00	9.992E-01	3.695E+00	6.641E+00	1.117E+01	2.737E+01	7.898E+01	4.008E+02	1.211E+03	2.566E+03	3.432E+03
2110.00	1.322E+00	3.128E+00	6.567E+00	1.282E+01	2.737E+01	7.898E+01	4.008E+02	1.194E+03	2.473E+03	3.283E+03
2115.00	1.303E+00	2.621E+00	5.425E+00	1.068E+01	2.737E+01	7.898E+01	4.008E+02	1.174E+03	2.403E+03	3.171E+03
2120.00	8.563E-01	2.250E+00	7.528E+00	1.945E+01	4.343E+01	9.698E+01	4.008E+02	1.154E+03	2.329E+03	3.059E+03
2125.00	9.716E-01	2.034E+00	4.503E+00	7.950E+00	2.737E+01	7.898E+01	4.008E+02	1.129E+03	2.242E+03	2.928E+03
2130.00	3.317E+00	5.130E+00	7.619E+00	1.137E+01	2.737E+01	7.898E+01	4.008E+02	1.103E+03	2.156E+03	2.793E+03
2135.00	6.904E-01	1.865E+00	5.152E+00	1.027E+01	2.737E+01	7.898E+01	4.008E+02	1.072E+03	2.053E+03	2.667E+03
2140.00	3.781E-01	1.881E+00	5.179E+00	1.056E+01	2.737E+01	7.898E+01	4.008E+02	1.041E+03	1.962E+03	2.537E+03
2145.00	6.701E-01	2.075E+00	5.105E+00	1.020E+01	2.737E+01	7.898E+01	4.008E+02	1.013E+03	1.879E+03	2.425E+03
2150.00	7.404E-01	3.010E+00	7.158E+00	1.132E+01	2.737E+01	7.898E+01	4.008E+02	9.844E+02	1.794E+03	2.313E+03
2155.00	1.071E+00	2.764E+00	3.852E+00	9.317E+00	2.730E+01	7.847E+01	3.991E+02	9.793E+02	1.940E+03	2.182E+03
2160.00	2.278E+00	3.689E+00	4.390E+00	1.009E+01	2.724E+01	7.798E+01	3.974E+02	9.734E+02	1.384E+03	2.052E+03
2165.00	7.181E+00	1.662E+01	1.327E+01	1.950E+01	4.301E+01	9.485E+01	3.947E+02	9.142E+02	1.669E+03	1.940E+03
2170.00	1.875E+00	3.291E+00	4.259E+00	9.634E+00	2.706E+01	7.665E+01	3.921E+02	8.524E+02	1.452E+03	1.828E+03
2175.00	1.827E+00	3.427E+00	4.512E+00	9.522E+00	2.700E+01	7.616E+01	3.895E+02	8.200E+02	1.368E+03	1.719E+03
2180.00	2.527E+00	4.172E+00	5.698E+00	1.061E+01	2.693E+01	7.563E+01	3.869E+02	7.876E+02	1.285E+03	1.611E+03
2185.00	3.735E+00	4.054E+00	4.945E+00	9.982E+00	2.684E+01	7.496E+01	3.808E+02	7.573E+02	1.213E+03	1.521E+03
2190.00	2.954E+00	3.606E+00	7.368E+00	1.186E+01	2.675E+01	7.429E+01	3.747E+02	7.270E+02	1.142E+03	1.432E+03
2195.00	2.142E+00	3.105E+00	7.455E+00	1.223E+01	2.661E+01	7.329E+01	3.642E+02	6.935E+02	1.071E+03	1.350E+03
2200.00	1.815E+00	3.917E+00	9.363E+00	1.298E+01	2.647E+01	7.224E+01	3.538E+02	6.600E+02	1.001E+03	1.268E+03
2205.00	1.286E+00	4.312E+00	9.371E+00	1.299E+01	2.614E+01	7.070E+01	3.398E+02	6.284E+02	9.469E+02	1.186E+03
2210.00	2.729E+00	6.528E+00	8.993E+00	1.217E+01	2.582E+01	6.916E+01	3.259E+02	5.969E+02	8.923E+02	1.104E+03
2215.00	2.707E+00	6.949E+00	8.700E+00	1.210E+01	2.555E+01	6.751E+01	3.023E+02	5.604E+02	8.476E+02	1.037E+03
2220.00	2.247E+00	6.594E+00	7.622E+00	1.145E+01	2.526E+01	6.586E+01	2.788E+02	5.240E+02	8.030E+02	9.701E+02

2225.00	1.829E+00	5.142E+00	6.409E+00	1.053E+01	2.434E+01	6.396E+01	2.570E+02	4.900E+02	7.524E+02	9.029E+02
2230.00	1.323E+00	4.704E+00	6.367E+00	1.053E+01	2.459E+01	5.207E+01	2.353E+02	4.560E+02	7.015E+02	8.358E+02
2235.00	2.036E+00	3.461E+00	4.786E+00	1.364E+01	2.413E+01	5.972E+01	2.162E+02	4.213E+02	6.395E+02	7.835E+02
2240.00	2.098E+00	3.118E+00	4.443E+00	1.286E+01	2.824E+01	5.203E+01	1.969E+02	3.867E+02	5.770E+02	7.313E+02
2245.00	2.472E+00	2.586E+00	3.963E+00	1.435E+01	2.976E+01	6.171E+01	1.856E+02	3.575E+02	5.298E+02	6.828E+02
2250.00	2.169E+00	2.261E+00	3.611E+00	1.458E+01	2.250E+01	5.289E+01	1.743E+02	3.285E+02	4.837E+02	6.343E+02
2255.00	1.803E+00	1.716E+00	3.154E+00	1.700E+01	2.331E+01	5.191E+01	1.656E+02	[illegible]	4.675E+02	5.932E+02
2260.00	1.468E+00	1.616E+00	3.352E+00	1.747E+01	2.456E+01	5.122E+01	1.568E+02	3.005E+02	4.549E+02	5.522E+02
2265.00	9.327E-01	1.268E+00	2.837E+00	1.827E+01	2.370E+01	4.864E+01	1.526E+02	2.863E+02	4.360E+02	5.075E+02
2270.00	9.114E-01	1.339E+00	3.732E+00	2.010E+01	2.304E+01	4.622E+01	1.464E+02	2.721E+02	4.178E+02	4.627E+02
2275.00	9.647E-01	1.303E+00	4.384E+00	1.723E+01	1.995E+01	4.161E+01	1.403E+02	2.483E+02	3.775E+02	4.141E+02
2280.00	9.667E-01	2.016E+00	5.159E+00	1.583E+01	1.619E+01	3.820E+01	1.342E+02	2.244E+02	3.374E+02	3.656E+02
2285.00	8.637E-01	2.483E+00	9.347E+00	1.461E+01	1.831E+01	3.668E+01	1.254E+02	1.963E+02	2.869E+02	3.134E+02
2290.00	7.164E-01	1.900E+00	6.890E+00	1.124E+01	1.441E+01	3.147E+01	1.167E+02	1.693E+02	2.365E+02	2.612E+02
2295.00	3.784E-01	2.108E+00	5.845E+00	9.853E+00	1.365E+01	3.429E+01	1.129E+02	2.120E+02	2.944E+02	3.392E+02
2300.00	9.524E-01	3.656E+00	5.800E+00	9.221E+00	1.380E+01	3.776E+01	1.091E+02	2.546E+02	3.522E+02	4.152E+02
2305.00	2.041E+00	3.549E+00	4.392E+00	7.079E+00	1.128E+01	3.224E+01	1.014E+02	2.057E+02	2.997E+02	[illegible]
2310.00	2.938E+00	3.048E+00	3.945E+00	7.290E+00	1.316E+01	3.193E+01	9.376E+01	1.566E+02	2.271E+02	2.453E+02
2315.00	2.134E+00	1.997E+00	2.731E+00	5.426E+00	1.105E+01	2.712E+01	8.788E+01	1.297E+02	1.732E+02	1.981E+02
2320.00	1.612E+00	1.516E+00	2.291E+00	5.465E+00	1.253E+01	2.592E+01	8.183E+01	1.005E+02	1.314E+02	1.509E+02
2325.00	1.294E+00	1.459E+00	2.159E+00	4.988E+00	1.168E+01	2.369E+01	7.330E+01	8.743E+01	1.114E+02	1.232E+02
2330.00	9.353E-01	1.137E+00	1.823E+00	4.488E+00	1.113E+01	2.172E+01	6.478E+01	7.433E+01	9.134E+01	1.075E+02
2335.00	6.604E-01	1.636E+00	2.002E+00	6.160E+00	1.435E+01	2.394E+01	5.796E+01	7.270E+01	9.211E+01	1.065E+02
2340.00	8.981E-01	1.174E+00	1.913E+00	5.165E+00	1.141E+01	2.127E+01	5.114E+01	7.103E+01	9.289E+01	1.056E+02
2345.00	9.333E-01	1.491E+00	2.650E+00	6.258E+00	1.100E+01	1.894E+01	4.272E+01	5.587E+01	7.135E+01	8.081E+01
2350.00	9.305E-01	1.956E+00	3.667E+00	6.818E+00	9.952E+00	1.603E+01	3.430E+01	4.068E+01	4.979E+01	5.602E+01
2355.00	1.040E+00	1.420E+00	2.266E+00	4.916E+00	7.899E+00	1.315E+01	2.723E+01	3.299E+01	4.096E+01	4.512E+01
2360.00	7.413E-01	9.584E-01	1.517E+00	3.421E+00	6.016E+00	1.041E+01	2.017E+01	2.529E+01	3.212E+01	3.423E+01
2365.00	9.176E-01	1.606E+00	1.405E+00	2.737E+00	5.071E+00	8.153E+00	1.586E+01	1.789E+01	2.093E+01	2.186E+01
2370.00	8.545E-01	9.706E-01	1.178E+00	2.037E+00	3.612E+00	5.501E+00	1.156E+01	1.033E+01	9.738E+00	9.484E+00
2375.00	8.774E-01	1.073E+00	1.219E+00	1.777E+00	2.678E+00	4.013E+00	7.470E+00	6.926E+00	6.757E+00	6.307E+00
2380.00	7.466E-01	9.768E-01	1.073E+00	1.431E+00	2.223E+00	2.812E+00	3.380E+00	3.506E+00	3.769E+00	3.131E+00
2385.00	6.464E-01	1.031E+00	1.209E+00	1.468E+00	1.791E+00	2.123E+00	2.425E+00	2.568E+00	2.825E+00	2.442E+00
2390.00	5.011E-01	8.588E-01	1.082E+00	1.277E+00	1.356E+00	1.384E+00	1.470E+00	1.630E+00	1.982E+00	1.753E+00
2395.00	1.960E+00	1.734E+00	1.389E+00	1.632E+00	1.910E+00	2.061E+00	2.189E+00	2.234E+00	2.253E+00	9.765E-01
2400.00	1.274E+00	8.986E-01	9.148E-01	1.044E+00	1.154E+00	1.227E+00	1.276E+00	1.289E+00	1.231E+00	1.290E+00

MEAN LINEWIDTH(W) ARRAY(CM-1/ATM, HWHM FOR NON-RESONANT SELF-BROADENING AT STP)

9.006E-02	9.000E-02	9.054E-02	8.955E-02	8.851E-02	9.234E-02	9.420E-02	9.696E-02	9.254E-02	9.638E-02
9.630E-02	9.768E-02	9.499E-02	9.443E-02	9.390E-02	9.662E-02	9.352E-02	9.230E-02	9.742E-02	9.580E-02
9.706E-02	1.006E-01	9.514E-02	9.781E-02	9.621E-02	9.454E-02	9.423E-02	9.380E-02	9.390E-02	9.361E-02
9.448E-02	9.712E-02	9.663E-02	9.667E-02	1.013E-01	9.988E-02	9.255E-02	8.741E-02	8.711E-02	8.671E-02
8.796E-02	8.830E-02	9.018E-02	9.276E-02	9.417E-02	9.532E-02	9.428E-02	9.527E-02	9.424E-02	9.344E-02
9.450E-02	9.353E-02	9.361E-02	9.314E-02	9.375E-02	9.390E-02	9.496E-02	9.558E-02	9.650E-02	9.834E-02
9.354E-02	9.854E-02	9.827E-02	9.741E-02	9.793E-02	9.633E-02	9.407E-02	9.399E-02	9.129E-02	8.894E-02
8.752E-02	8.634E-02	8.490E-02	8.329E-02	8.134E-02	8.178E-02	8.164E-02	8.365E-02	8.763E-02	8.378E-02
9.332E-02									

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space and missile systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch and reentry aerodynamics, heat transfer, reentry physics, chemical kinetics, structural mechanics, flight dynamics, atmospheric pollution, and high-power gas lasers.

Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Physics Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

THE AEROSPACE CORPORATION
El Segundo, California